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Hydro EcoNex

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HYDROLOGICAL INVESTIGATIONS IN THE DNIESTER RIVER ECOSYSTEMS

CREATING A SYSTEM OF INNOVATIVE TRANSBOUNDARY MONITORING OF THE TRANSFORMATIONS OF THE BLACK SEA RIVER ECOSYSTEMS UNDER THE IMPACT OF HYDROPOWER DEVELOPMENT AND CLIMATE CHANGE

BSB 165 - HydroEcoNex

On the front cover of brochure - vil. Chobruch, the beginning of the branch Turunchuk

On the back of the brochure cover - hydrological observations on the Dniester River, vil. Olonesti

Recommended for publication by the Technical Council of the Hydrometeorological Centre for Black and Azo v Seas 08/28/2021

BSB 165 - HydroEcoNex

This brochure presents the Project *"**Creating a system of innovative trans-boundary monitoring of the transformation of the Black Sea river ecosystems under the impact of hydropower development and climate change"*** **(Acronym: *HydroEcoNex*)**.

This project is realized under the "Joint Operational Programme Black Sea Basin 2014-2020", which is one of the four maritime programmes, estab-lished in the framework of the European Neighborhood Instrument (ENI) 2014-2020 — the Programming document for EU support of ENI Cross-Border Cooperation (CBC). Such cooperation on the EU external borders is a key priority in the European Neighborhood Policy (ENP) and contributes to the ENI overall objective of the progress towards shared prosperity and good neighborliness between EU Member States and their neighbors.

Joint Operational Programme BLACK SEA BASIN 2014-2020
Implementation period: **21.09.2018-20.09.2021** (36 months).
The total budget of the project is 896,865.00 EURO.

The main goal of the HydroEcoNex project is the development of the unified system of innovative environmental monitoring for the provision of the data and the information essential for the transboundary and sustainable long-term assessment of the observed environmental changes in the Black Sea Basin's river ecosystem, impacted by the changes in the hydropower operation due to the effects of the climate change.

The following objectives were set in order to achieve the project main goal:

1. to elaborate the system of monitoring an influence of the hydropower on state of the environment and the services delivered by the ecosystem of the Black Sea Basin Rivers;
2. to develop the policy instruments and to enhance humans capacities for integrated water resource management in light of impacts caused by the hydropower and climate changes;
3. to manage, to broadcast and to disseminate the knowledge towards strengthening of the transboundary cooperation in monitoring the impact of hydropower and climate changes on the rivers' ecosystems.

PROJECT OVERALL OBJECTIVE -

Development of the unified innovative system for an environmental assessment with aim to provide data and information essential for the monitoring of changes in the Black Sea basin ecosystem, caused by the impact of the hydropower and long-term effect of the global climate change.

PROJECT AREA

The project is implemented for the area in the basins of two transboundary rivers — r. Dniester and r. Prut.
Assessment of the environmental impact was considered for:

- ➢ the Dnestrovsk hydropower complex (DHPC) — (left, Fig.1), formed by two hydropower plants (HPP-1 and HPP-2),
- ➢ Dnestrovsk pumped-storage hydropower plant — large plants located not far from the Ukrainian-Moldovan border,
- ➢ Dubasari hydropower plant (right, Fig.1), located on the Dniester River on the Moldovan territory,
- ➢ and Costeti-Stinca hydropower plant, located on the Prut River.

Fig. 1. Ukrainian hydroelectric power plants on the Dniester River

THE PROJECT PARTNERS:

Institute of Zoology, the Republic of Moldova
The institute conducts fundamental and applied research t is focused on the research of structural and functional organization, dynamics and evolution of animal populations and communities, elaboration of methods of conservation and sustainable use of animal world.
http://www.zoology.asm.md/

International Environmental Association of River Keepers Eco-Tiras, the Republic of Moldova
Eco-Tiras is a transboundary association of Moldovan and Ukrainian environmental NGOs, located and working in the Dniester River basin.
www.eco-tiras.org

"Dunarea de Jos" University of Galati, Romania
The university is a public higher education institution founded in 1974, which prepares specialists in various domains, including ecology and environmental protection, environmental engineering, environmental chemistry, agriculture, pisciculture, etc.
www.ugal.ro

Ukrainian Scientific Center of Ecology of the Sea
The center has multiple tasks on ecological monitoring within the Black and Azov Seas. In accordance with the Strategic Action Plan for Rehabilitation and Protection of the Black Sea.
http://www.sea.gov.ua/

Hydrometeorological Center for Black and Azov Seas, Ukraine
The main directions of activity are the provision of population and organizations of all types of ownership with hydrometeorological information, environmental monitoring data, warning and notification on dangerous natural phenomena, and the development of hydrometeorological forecasts.
http://www.hmcbas.od.ua/

Hydrometeorological Centre for Black and Azov Seas (HMCBAS) was founded in 1865 on the base of Novorossiysk University of Odessa. The main directions of its activity are the provision of population and all type ownership organizations with hydrometeorological information and environmental monitoring data, the warning and notification on dangerous natural phenomena and hydrometeorological forecasts. Currently, HMCBAS offers information and forecasting services: synoptic forecasts and hydrological forecasts of the state of rivers in the South of Ukraine, preparing operational forecasts on the state of the sea water area in the Ukrainian part of the Azov and Black Seas basins.

The nowadays network of sea meteorological observations is part of a terrestrial subsystem for obtaining the hydrometeorological data in coastal zone, including stations and posts located in the river estuaries of Ukraine. At some of them the observations on atmosphere and sea water parameters have been carried for more than 200 years. The unique sets of such multiyear data, obtained during coastal hydrometeorological observations, are of great scientific value for the study and prediction of global and regional climate change. HMCBAS also has the ability to analyse the entire hydrometeorological information of the Dniester River basin over the last 50-100 years. It has production units on the whole territory of Southern Ukraine, performing a permanent monitoring of sea environment (hydrology, hydrochemistry), air (temperature, humidity, precipitations, wind speed, visibility, pollution, actinometrical) and river hydrology (streamflow, water level, ice, temperature, hydrochemistry), etc.

The organization structure of HMCBAS in-clouds: Department of hydrometeorological service and maintenance; Department of meteorological forecasts; Department of sea and river hydro-logical forecasts; Department of agricultural meteorology; Department of meteorology; Certified hydrochemical laboratory for analysis of sea water and soil; Laboratory of air pollution observations, and Observing network of marine and river hydro-meteorological stations. HMCBAS is also an executants of the oceanographic part of the National Antarctic Centre programme at the Ukrainian Antarctic Station “Academic Vernadsky” where its main role is investigation and analysis of peculiarities of sea water regime and variability of its parameters as well as observation and study of hydrometeorological conditions here.

Since 2006, HMCBAS has been publishing the Bulletin of Hydro-meteorological Centre for Black and Azov Seas. Its employees are the authors of scientific publications for climate change in the northern Black Sea region and its influence on possible changes in the social conditions of the region. One of the last and important works is the monograph “North-western part of the Black Sea: the structure and climatic variability of oceanological fields” [1]. The HMCBAS's employees were involved as experts in the field of hydrology, oceanology and climatology in different Ukrainian and international projects.

In the HydroEcoNex project, HMCBAS in cooperation with UkrSCES, will contribute to the analysis of historical data and collection of recent relevant data on ecosystem changes under the impact of hydropower and climate changes. Within the framework of the project, the HMCBAS will model also the changes in basic climatic parameters of the atmosphere (temperature and precipitation) throughout the Dniester River basin for the period up to 2050. The results will be used as a basis for modelling the changes of certain hydrobiological parameters of the Dniester ecosystems that will be taken into account for developing recommendations for an optimal use of the Dniester River's resources by all countries of the region. HMCBAS will organize and actively participate in seminars for the exchange of information and research results with interested organizations. Based on these activities, HMCBAS will con-tribute to the development of a strategy for bilateral water cooperation on joint ecological monitoring of transboundary rivers affected by hydropower and climate change. The results of HMCBAS activity will be presented at the Project's final International conference and disseminated to riparian Dniester communities both close to the hydro-power plants and those located in the Low Dniester and its estuary.

Steering Committee of HydroEcoNex project (fig. 2)

Institute of Zoology: cor. member of ASM, prof. Dr. Hab., *Elena Zubcov*, project manager, email: elzubcov@mail.ru, Phone: +37379638311

International Association of River Keepers Eco-Tiras: Dr. *Ilya Trombitsky*, email: ilyatrom@mail.ru, Phones: +37369121726, +37322225615

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Hydrometeorological Centre for Black and Azov Seas: Dr. Alexander Matygin, email: acm32alex@gmail.com, Phone: +380503953295

Fig. 2. Steering Committee of HydroEcoNex project:
Dr. *Ilya Trombitsky*, Prof. Dr. Habil, *Antoaneta Ene*, cor. member of ASM, prof. Dr. Hab., *Elena Zubcov*, Dr., Assoc.profess., *Svetlana Kovalishina*, Dr. *Alexander Matygin*

1. Enlarging opportunities for monitoring of aquatic ecosystems — acquiring new research equipment

In order to update the technical base and enforce the capacity of the institutions for aquatic monitoring of hydropower impact, new equipment was purchased by HydroEcoNex partners.

Hydrometeorological Centre for Black and Azov Seas purchased a multiparameter instrument — the hydrological sonde EXO1 that collects water quality data (Fig.3). Figure 4 shows all types of hydrometeorological observations that are carried out by employees of the GMC CHAM in expeditionary work.

The sonde collects the data with up to four user replaceable sensors and an integral pressure transducer. Each sensor measures its parameter via a variety of electrochemical, optical, or physical detection methods. Each port accepts any EXO sensor and automatically recognizes its type. Depending upon user-defined settings, the EXO1 will collect data and store it on board the sonde, transfer the data to a data collection platform

The sonde is designed for high-precision determination of hydrological, hydrochemical and hydrobiological parameters of river and sea waters: immersion depth of sensors, temperature, electrical conductivity (salinity), dissolved oxygen content, turbidity, fluorescent dissolved organic matter, ammonium, nitrate, chloride, pH, Rhodamine, total algae. Not only will these sensors provide the most accurate and fastest response temperature data, but it will also provide the best data for the use in temperature compensation for the other EXO probes.

Fig. 3. Multiparameter hydrological sonde EXO1 that collects water quality data

The principle of operation of the EXO optical dissolved oxygen sensor is based on the well-documented concept that dissolved oxygen quenches both the intensity and the lifetime of the luminescence associated with a carefully chosen chemical dye.

Turbidity is the indirect measurement of the suspended solid concentration in water and is typically determined by shining a light beam into the sample solution and then measuring the light that is scattered off of the suspended particles. Turbidity is an important water quality parameter and is a fundamental tool for monitoring environmental changes due to events like weather-induced runoff or illicit discharges. The source of the suspended solids varies (examples include silt, clay, sand, algae, and organic matter) but all particles will impact light transmittance and result in a turbidity signal.

The EXO Turbidity sensor employs a near-infrared light source and has been characterized as a nephelometric near-IR, nonratiometric sensor in accordance with ASTM Method D7315-07a.1 This method calls for this sensor type to report values in formazin nephelometric units (FNU), which is the default calibration unit for the EXO sensor.

Fig. 4. Types of hydrometeorological observations carried out by employees of the HMC BAS in expeditionary work

2. Building of the transboundary cooperation in the joint monitoring of the impact of hydropower development in the Dniester and Prut River basins

HydroEcoNex project, as part of the Black Sea Basin Programme, it is expected to improve contacts between different beneficiaries in the programme area, to establish sustainable networks, capable to address common challenges in environment. As the project aims to provide a real contribution to the improvement of joint environmental monitoring (Priority 2.1 of the programme), it includes a range of joint events.

Joint research trips

In 2019-2021, members of the project team from the Institute of Zoology, the Ukrainian Scientific Centre for Marine Ecology and the Hydrometeorological Centre for Black and Azov Seas, as well as employees of the Lower Dniester National Park, Odessa I. Mechnikov National University and Odessa State Ecological University (fig. 5) made joint production trips to obtain hydrological information and for the collection of hydrobiological and hydrochemical samples from the Dniester River. The trips provided the participants with valuable experience, as they had the opportunity to exchange knowledge and skills on sampling methodology, equipment and sample processing in the field (filtration, pre-processing of bacterioplankton, phytoplankton, zooplankton and zoobenthos samples).

Fig. 5. Participants in joint sampling near Palanca, Lower Dniester, August 2019 (left); LP, PB4, PB5 team during summer industrial practice on the Dniester river and vil.. Chobruch, June and July 2021

More than 20 expeditions along the Dniester were conducted, of which 5 were joint with LP and PB5, and 23 jointly with the Lower Dniester National Park, Odessa National University and Odessa State Ecological University. In total HMC BAS, within the framework of expeditionary studies under the project HYDROECONEX, carried out more than half a million measurements of the parameters of the waters of the Dniester River, Turunchuk River, Beloe and Pogoreloe Lakes and Dniester Estuary.

3. Hydrological investigations in the Dniester River ecosystems

The impact of a hydropower development on the hydrological and ecological regime of rivers is multiple and extremely complex due to the interaction of various factors and the possibility of hard-to-predict consequences, especially if taking into account the recent decades' climate changes. Unfortunately, hydropower activity has not only positive effect, but, if mismanaged, it could lead to such significant negative consequences with such substantial impact, that damages to the aquatic ecosystem could be sometimes irreversible and irreparable.

In this aspect, it is hugely important to monitor the change in the hydrological and ecological regime and its distribution in time and space. In particular, it is essential to carry on the representative screening of the flow rate, temperature, salinity, turbidity of river waters, the concentration of dissolved oxygen, the content of nutrients, the rate of production processes, destruction of organic matter and hydrobionts, and, as a consequence, deterioration of river water quality and biological productivity of aquatic ecosystems.

Zoning of the Dniester basin

Natural mechanisms investigations and river runoff formation conditions investigations in a specific separate river basin, the hydrological situation impact on the ecosystems of the river itself and the ecosystems of the entire water basin require an identification of areas within which the natural conditions and the degree of their impact on ecosystems are sufficiently homogeneous.

Dniester River basin could be zoned into three parts (Fig. 6) accordingly to the, water regime, water supply sources, physical and geographical features:

- Upper “Carpathian” (from the from the very river source to Nizhnee village at the river Tlumach mouth, 296 km length);
- Middle “Podolsky” (from Nizhnee village to the Dubossary HPP, 715 km length);
- Lower (from the Dubossary Hydro Power Plant (HPP) dam to the Dniester mouth, 351 km length).

Also, the Dniester basin can be divided into three parts: Carpathian (before the confluence of the Bystritsa river with the Dniester river); Volyno-Podolskaya part (to the villages of Kamenka-Senatovka, 473 km upper the mouth); Southern (from Kamenka village to the Dniester river estuary) according to its climatic and orographic features.

The Dniester reservoir and the Dniester HPS, which were built and put into operation in the period from 1975 to 1983, significantly changed the hydrological and ecological situation in the Dniester basin. From this point of view, the hydrotechnical complex can be considered as a new basin zoning border, which divides the catchment into two sections, the upper one with an area of 40,500 km^2 and the middle and lower ones with a total area of 31,600 km^2.

Fig. 6. Zoning of the Dniester basin by water regime, water supply sources and physical and geographical features

Evaluation of the impact of hydropower structures on the Dniester River runoff and the river ecosystem in the face of climate change

Annual runoff calculating

Evaluation of the impact of hydropower structures on the Dniester River runoff and the river ecosystem in the face of climate change suggests the presence of long-term series of hydrological parameters. The analysis of the long-term series will allow formulate the relevant conclusions.

However, currently there is no reliable data would allow to determine the annual flow from the entire catchment area directly at the Dniester River estuary.

The situation can be explained by the fact, that it is extremely difficult to set up the representative hydrological gauging stations (further by the text — HGS) network on the lower section of the Dniester River. The main Dniester riverbed there is divided into two branches — Dniester and Turunchuk near the Chobruchy village 68 km downstream the Bender city.

Then the branches merge again into the common Dniester channel, about 7 km above the village of Mayaki.

The representativeness of the hydrometric observations data was being received directly at the river mouth for the purposes of the annual runoff calculating is questionable, mainly due to the presence of numerous small river channels and floodplain lakes, which have significant accumulative, transforming and redistributive capacity.

In addition, changes in wind direction over the water area of the Dniester Liman can cause a significant increase or decrease in the water level upward from the estuary for a considerable distance in the very channel of the Dniester. This factor also introduces significant distortions in the calculation of the true water discharge at the mouth of the river.

The most representative and comprehensive long-term hydrological data that could be used for reliable evaluation of the annual Dniester flow are registered and collected at Bender hydrological gauging station. The Bender hydrological gauging station records data on the Dniester runoff from a catchment area of 66100 km^2 (91.7 % of the entire Dniester catchment area). The hydrological observations have been conducted here since 1881.

The long-term average value of the Dniester annual flow at Bender HGS is estimated as value in 9.24 km^3 [2].

Several small rivers collect to the Dniester River downstream the Bender city. There are: Zolotaya, Okna, Rybnica, Belochi, Yagorlyk, Kuchurgan rivers. The small rivers summary annual flow is estimated at 0.12 km^3, that approximately is 1.3 % of the total Dniester annual discharge volume.

The solution to the problem of the annual runoff calculating from the entire catchment area directly at the lowest hydrological station Mayaki was found thanks to the availability and analysis of up-to-date data of daily observations of the water level at the Troitskoye and Nezavertaylovka HGSs on the Turunchuk River and at the Mayaki HGS on the Dniester River.

The Mayaki HGS observes water level for many years. In addition, the HGS makes detailed water discharge measurements from time to time.

As it has been already noted above, river water level at the Mayaki HGS significantly depend on the duration, direction and strength of the wind. In this regard, the process of determining a reliable interdependence of the water flow rate on the level (Q = f (H)) for this HGS becomes very complicated and therefore requires additional data.

We had analyzed the water levels data at Mayaki HGS Dniester river, Troitskoye OUVH HGS and Nezavertailovka HGS — Turunchuk river (hereinafter Turunchuk). We identified a close correlation between measured water discharges at Mayaki HGS and corresponding daily water levels at these three HGS as a result.

The relationship between water discharge, QM (m^3/s), at Mayaki HGS and water surface slope on the river section between Troitskoye HGS and Mayaki HGS is quite well approximated by equation in exponential form [2]:

$$Q_M = 90 \cdot e^{35 \cdot I_{T\text{-}M}} \quad (1),$$

where:

Q_M is the average daily water discharge at the Mayaki HGS, in $\mathbf{m^3/s}$;

$I_{T\text{-}M}$ is the river water surface slope on the river section between Troitskoye HGS Turunchuk and Mayaki HGS Dniester, expressed in **ppm (‰)**.

Water discharge relationship with water level or with water surface slope at the Mayaki, Dniester and Nezavertailovka, Turunchuk river section is also defined in an exponential form (Fig. 7) and it is represented by the formula:

$$Q_M = 90 \cdot e^{25.3 \cdot I_{N\text{-}M}} \quad (2),$$

where:

Q_M is the average daily flow rate at Mayaki HGS, in $\mathbf{m^3/s}$;

$I_{N\text{-}M}$ is the slope of the water surface on the river section between Nezavertailovka and Mayaki OSEU HGSs, expressed in **ppm (‰)**.

A similar graph for the years with runoff volume below the long-term average of 9.24 km^3 was plotted and analyzed for the reason to increase the accuracy of the calculation.

Calculation formula for such years is adopted as follows:

$$Q_M = 80 \cdot e^{26 \cdot I_{N\text{-}M}} \quad (3)$$

The formulas (1, 2, 3) make it possible to calculate the average daily water discharge in the presence of data from observations of the water level and, accordingly, to determine the annual runoff characteristics.

The values of the runoff volume obtained by formulas (1, 2, 3) for the period from 1993 to 2020 for Mayaki HGS and the measured annual runoff at Bendery HGS for the same period, make it possible to determine the correlation coefficient of the runoff volumes at these two points (Fig. 8).

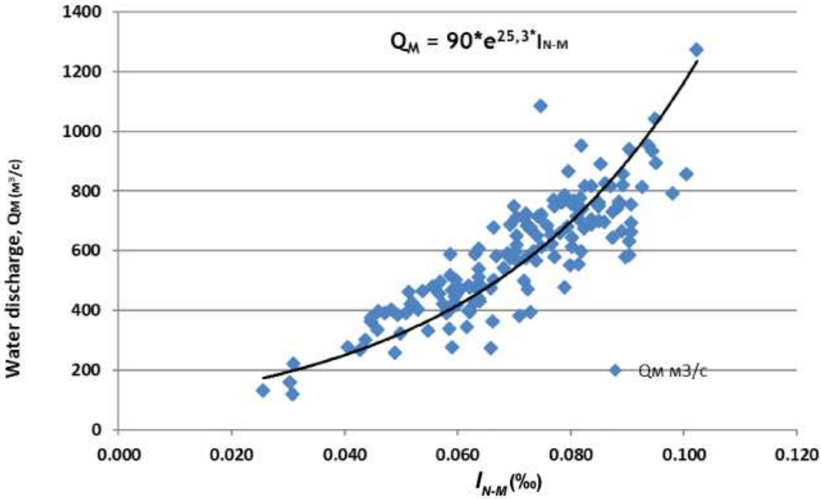


Fig. 7. Water discharge (QM) and Water surface slope (IN-M (‰)) in the section Nezavertaylovka HGS and Mayaki HGS relationship

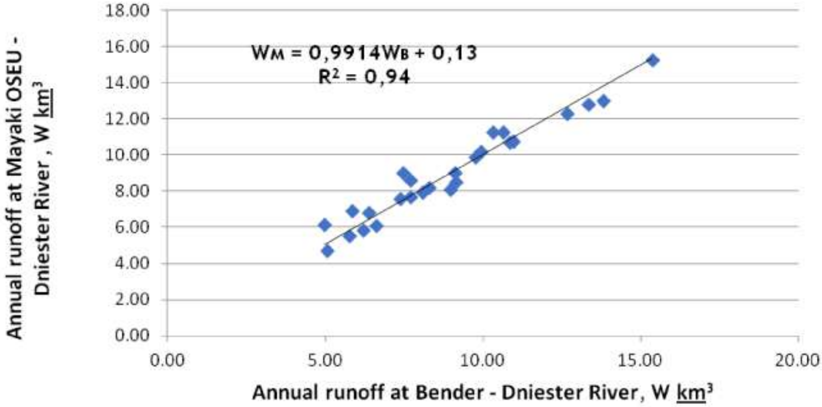


Fig. 8. Relationship between annual Dniester runoff volumes at Mayaki HGS and annual Dniester runoff volumes at Bender HGS, for the 1993 to 2020 period.

The relationship is expressed by the linear regression equation:

$$W_M = 0.9914 \cdot W_B + 0.13 \quad (4),$$

where: W_M is the volume of annual runoff at Mayaki HGS, in km³;

W_B is the annual runoff at Bender HGS, in km³.

A correlation coefficient R in the regression equation (4) reaches 0.97 (R = 0.97).

The coefficient indicates a very close statistical, practically functional relationship between the amount of runoff at Bender HGS and in Mayaki HGS.

The Dniester runoff calculations for the period from 1985 to 2020 were carried out on the basis of the water level observations at the Mayaki HGS, Troitskoe HGS, Nezavertaylovskoe HGS and according to the annual runoff volumes data at the Bendery HGS.

Hydrological analysis

For a comparative analysis of the total runoff of the Dniester River, starting from 1946, data on the measured level and discharge of water were used for:

- Zalishchyki HGS, catchment area — 24600 km^2, the upper part of the Dniester basin;
- Mohyliv-Podilskyi HGS, catchment area 43000 km^2, middle part of the basin;
- Bender HGS, catchment area 66100 km^2, the lower part of the basin.

And also, the data of observations at the Mayaki HGS, the catchment area is 72000 km^2, which is located below all posts downstream, where only the water level is monitored daily.

The data of the level and water discharge daily observations, air temperature and precipitation were taken from the archive of the Hydrometeorological Centre for Black and Azov Seas, Odesa, Ukraine. The values of water discharge and runoff volume at the Mayaki HGS were obtained using the calculated analytical formulas [2].

Runoff state of the Lower Dniester

The current environmental and anthropogenic conditions have led to the decrease in the total water content of the Dniester River, which for almost 10 years do not be able to reach the value of the statistical "norm" estimated as a long-term average of 9.2-10.2 km^3 [2, 3] The phase of low water content, which began in 2011 (Fig. 9, 11), in 2016, reached the minimum value of the annual runoff volume of 4.74 km^3 at the outlet section at the Mayaki HGS (catchment area 72.000 km^2). In 2018, 2019, 2020 the annual runoff at the Mayaki HGS was 7.67, 7.89 and 7.57 km^3 , respectively.

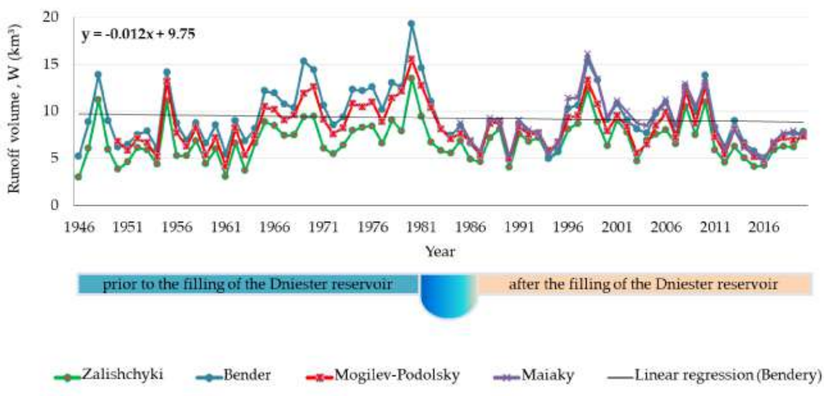


Fig. 9. Combined hydrograph of annual runoff volumes for the 1946-2020 period within selected HGSs

Low-water period flow rates in the same years, thanks to releases from the Dniester reservoir, were kept at the level of 145-155 m^3.s^{-1} at the Mayaki HGS. At the same time on the Dniester River, in the Chobruch-Olonesty section, the estimated discharge reached 65 m^3.s^{-1}, and on the Turunchuk river, on the Chobruch-Belyayivka section — 85 m^3.s^{-1}. The maximum average daily discharge during the floods of 2018, 2019 and 2020 at the Mayaki HGS reached values of 850, 1100 and 1300 m^3.s^{-1}.

Accordingly, at the Mayaki HGS:

- average maximum flow velocity during floods period is 1.25-1.35 $m \cdot s^{-1}$;
- average minimum stream flow velocity in autumn-summer low-water period is 0.15-0.25 $m \cdot s^{-1}$.

At Palanca "temporary gauging station" point:

- average maximum flow velocity during floods is 1.1-1.2 $m \cdot s^{-1}$;
- average minimum flow velocity in autumn-summer low-water period is 0.10-0.20 $m \cdot s^{-1}$.

The main difference between the selected stations is that Palanca is the furthest upstream point on the border of Ukraine with Moldova, and Mayaki station is located below the confluence of the Turunchuk and Dniester rivers. The width of the river in the Palanca site is up to 80 m, average depth is 3.2 m. In 2018-2020 an average annual runoff volume reaches about 3.32 km^3, average annual discharge — 105 $m^3 \cdot s^{-1}$, average flow velocity was 0.32 $m \cdot s^{-1}$, varying from 1.1-1.2 $m \cdot s^{-1}$ during floods down to 0.15-0.25 $m \cdot s^{-1}$ during the autumn-summer low-water period. The river width at the Mayaki site reaches up to 180 m, average depth is 3.4 m, average annual runoff volume is 7.71 km^3, average annual discharge — 245 $m \cdot s^{-1}$. Within the study period, average flow velocity was 0.35 $m \cdot s^{-1}$, varying from 1.25-1.35 $m \cdot s^{-1}$ during floods down to 0.15-0.25 $m \cdot s^{-1}$ during the autumn-summer low-water.

Long-term dynamics of the runoff

In official documents, as well as in various publications, it is usual to describe the annual runoff of the Dniester River at about 9,2-10.2 km^3. This value (as will be shown below) is based on its average value, usually obtained from the longest available series of representative observations.

The data relating to long-term observations on water discharge at the hydrological stations Zalishchiki, Mohyliv-Podilskyi, Mayaki (Ukraine) and Bender (Moldova) were used initially. The choice of these stations was dictated, on the one hand, by the need to correctly identify the impact of the functioning of the hydroelectric power plants and their reservoirs, as well as to identify climate impact on the river flow below the dams, and, on the other hand, by the accessibility of available information.

Long-term hydrological data on the Lower Dniester runoff should be distinguished into two main periods: 1946-1981 before the filling of the Dniester reservoir and 1987-2020 when Dniester reservoir and HES-1 were put into operation. The influence of Dubossary HPP, put into operation in 1955, was not taken into account, because of its low impact on the total discharge of the river. The main difference between these periods is that the first one is characterized by stable climate, and the other one is characterized by a global warming influence, starting in the middle of 1990s. The combined hydrograph of annual runoff volumes for the period from 1946 to 2020 for each of the four stations is shown below (Fig.10).

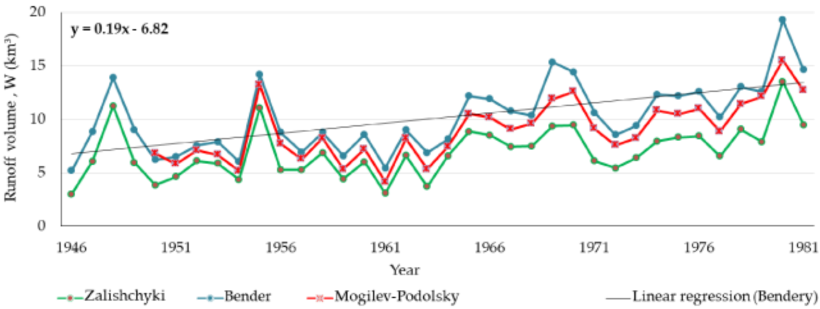


Fig. 10. Combined hydrograph of the annual runoff volumes for the 1946-1981 period within selected HGS

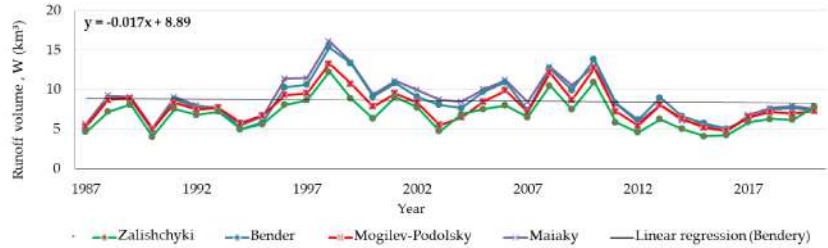


Fig. 11. Combined hydrograph of the annual runoff volumes for the 1987-2020 period within selected HGS

A trend line with a linear regression coefficient -0.012 shows a downward trend in the total discharge of the Dniester River at all the stations. We suggest that this trend is due to general climatic changes that began to manifest themselves in the mid-1980s.

The degree of the Dniester reservoir impact on the lower Dniester total discharge, regarding the influence of climatic changes, can be calculated by the analysis of the statistical relationship between the runoff at the Bender HGS and Zalishchyki HGS before and after the reservoir was filled.

The runoff data at the Bender HGS should be divided into two periods:

1) 1946-1981 — the period prior to the filling of the Dniester reservoir.

The linear regression equation $y = 0.19x - 6.82$.

2) 1987-2020 — the period after the filling of the Dniester reservoir.

The linear regression equation $y = -0.017x + 8.89$.

The series of runoff data from 1946 to 1981 (the year when the Dniester reservoir began to fill) may be considered homogeneous, since the main influence on the discharge was exerted by natural factors. The 1986-2020 data series is also homogeneous because of the emergence of a significant factor influencing the Lower Dniester flow. This factor is the reservoir, capable of holding up to 1/3 of the total annual river flow. At first time interval, the trend line has a positive regression coefficient of 0.19 and shows that the water content acquired a local growth trend. For the second period, a trend line with a negative regression coefficient of -0.017 shows a decrease in the annual runoff.

Dependence of the Dniester annual river flow volume at Bender HGS on the flow volume at Zalishchiki HGS, for the periods 1946-1981 and 1986-2020, is shown below (Fig. 12)

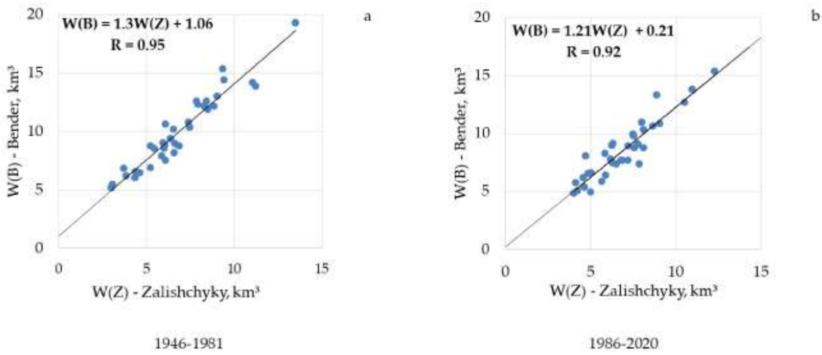


Fig. 12. The annual runoff volume W(B) at Bender and W(Z) - Zalishchyki HGS statistical dependence for the period a) 1946-1981 and b) 1986-2020

The regression line on each of the graphs demonstrates a close linear relationship between the volumes of annual runoff in Bender HGS and Zalishchyki HGS. The correlation coefficient between the runoff in Bender and Zalishchyki is R = 0.95 (for the observation period 1946-1981) and R = 0.92 (for the observation period 1986-2020). These correlation coefficient values suggest a very high statistical dependence of the annual runoff in Bender with the corresponding runoff in Zalishchyki.

The linear regression equations for these periods are the following:

$$W(B) = 1.30 \cdot W(Z) + 1.06 \quad (5)$$

$$W(B) = 1.21 \cdot W(Z) + 0.21 \quad (6)$$

The analysis of linear regression equations (5) and (6) shows that the multiplier of the variable in the first regression equation is 1.3. This value allows us to conclude that in the period of high-precipitation years (1946-1981), the annual runoff in the catchment area from the Zalishchiki HGS to Bender HGS due to lateral inflow increased, on average, by 1.3 times.

After the onset of a prolonged phase of lowering water volume and filling the reservoir, the same river flow increment coefficient (the coefficient of linear regression in the second equation) had decreased to 1.2, i.e. by 8.3 % from 1986 to the present. This difference between the coefficients contains, in an implicit form, irrecoverable losses from the reservoir by evaporation and infiltration into the groundwater horizons that do not have a recharge into the river channel, as well as irreversible losses for water management needs.

The value of the constant in these linear regression equations is also significantly different, which can be interpreted as the runoff increase in the Zalishchiki-Bender section because of groundwater supply. If the volume of the annual runoff in Zalishchyki is theoretically equal to zero, in 1946-1981, the runoff in Bender could reach a value up to 1 km^3. In the period with a steady downward trend in water availability (1986-2020), groundwater reserves and possible insignificant surface runoff from the catchment area between Zalishchiki and Bender may provide only a runoff of 0.21 km^3, if there is no discharge through the Dniester HPP dam.

The impact of the Dniester HPP and the reservoir is clearly visible on the shape of the hydrograph of average daily discharges in the Mohyliv-Podilskyi HGS. Comparison of the hydrographs “before and after” demonstrates a significant difference in the daily fluctuations in water level and discharge. Before the appearance of the HPP dam, the diurnal variation of the river levels had a smooth appearance both in the low-water period and during floods. After the HPP commissioning, the course of the levels and, accordingly, the hydrograph of water discharges took the form of a sinusoid with a high frequency of daily fluctuations (Fig. 13, 14).

A decrease in the maximum flow rates during floods, due to the transforming and smoothing effect of the Dniester and the Dubossary reservoirs, leads to a significant deterioration in the “washing” of the riverbed and cleansing from silt deposits, especially in the lower river. This negative phenomenon is especially manifested in years of medium and low water levels. The positive effect of the influence of the Dniester reservoir is illustrated above (Fig. 14) where the hydrographs for years with a minimum annual runoff of about 4 km^3 are shown. In 1961, when the Dniester runoff depended only on climatic factors, the water discharge in Mogilev-Podolsk decreased to 50 cubic meters per second during low-water periods. In 1990, as in other dry years (in particular in 1987, 1994, 1995, 2015, 2016), the availability of water reserves in the reservoir made it possible, through regular releases, to ensure the minimum water discharge within 120-150 cubic meters per second, practically throughout the entire low-water period. This operating mode of the Dniester reservoir improved the filling of the Lower Dniester channel with the water necessary for its ecosystem.

It should be emphasized that the runoff decreasing problem and water scarcity in the Middle and Lower Dniester have manifested itself particularly after the Dniester reservoir was constructed.

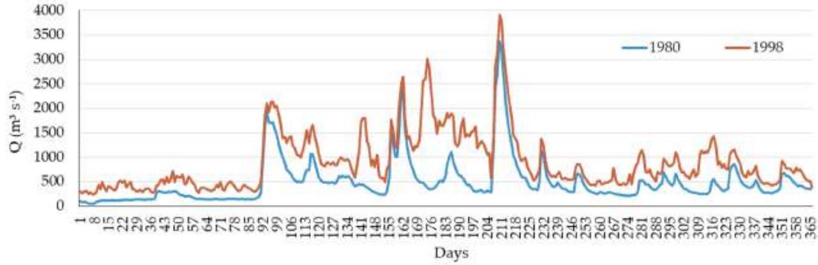


Fig. 13. The annual hydrographs of water discharges at **Mohyliv-Podilskyi HGS** for 1980 and 1998 "before and after" years with the maximum annual runoff

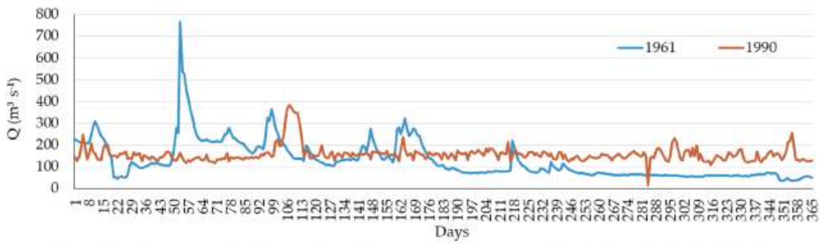


Fig. 14. The annual hydrographs of water discharges at **Mohyliv-Podilskyi HGS** for 1961 and 1990 "before and after" years with the minimum annual runoff

But! The problem of decrease in runoff is largely associated with a significant reduction in water inflow from tributaries flowing into the Dniester below the Mogilev-Podolsk HGS.

The long-term tendency towards a decrease of precipitation on the territory of the Middle and Lower Dniester (Fig. 15), a stable tendency towards an increase in the average annual air temperature (Fig. 16) largely determine on these catchments the runoff formation conditions.

The conditions have already led to the decrease in the total water volume of the Dniester River, which for almost 10 years has not been able to reach the value of the statistical "norm". As mentioned above, the norm or long-term average value of the total annual runoff of the Dniester, with different assessment methods, is taken to be from 9.2 to 10.2 km³ [2, 3].

As already mentioned, two large riverbed reservoirs, together with hydroelectric power plants, were built on the main channel of the Dniester River in the second half of the 20th century. The functioning of these hydrotechnical complexes is currently a significant regulating factor that affects the flow of the river in its middle and lower parts. The presence of this regulating factor has both positive and negative consequences for the river ecosystems and water economy of the region.

The total flow of the river has undergone significant transformation and redistribution over the time. The water balance was changed. Stream velocity had decreased in the reservoir part. Suspended particles runoff ("solid runoff") had decreased below the dams. The river hydrochemical regime changed too.

The dams of the Dniester HPPs, not equipped with fish passages and elevators, have changed the natural transit type of migration of higher aquatic organisms. The entire natural hydrobiological cycle of the river transformed too. The cycle is acquiring features more proper for closed water bodies.

The assessing methods of the river runoff regulation processes and other anthropogenic impacts on the ecosystems of the lower Dniester and Dniester estuary water areas require the creation of a new, more detailed modern data base.

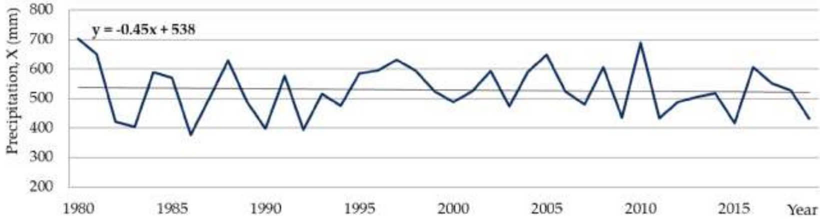


Fig. 15. The sum of annual precipitation,
averaged over the Middle and Lower Dniester basin in the 1980-2020 years

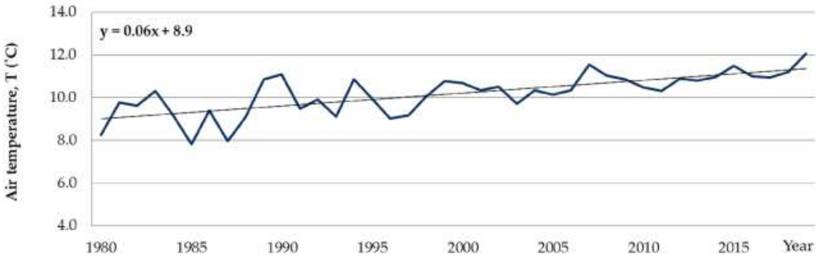


Fig. 16. Average annual air temperature
in the catchment area of the Middle and Lower Dniester, T (^{0}C)

The measurement data, which can now be found in already published scientific papers, indicate that measurements of water parameters in the main channel of the lower Dniester, in the Turunchuk arm, in floodplain lakes and at the mouth of the Dniester were carried out only at a limited number of points on the measuring verticals with using hydrological thermometers and by taking water samples with bottles bathometers [4].

One of the important goals of our study is to obtain relevant data with a high degree of detail for studying the modern spatial and temporal structure of the hydrological and hydrochemical fields of these rivers, lakes and estuary part.

Modern spatial and temporal structure of the hydrological and hydrochemical fields the Dniester estuary

The international project "HydroEcoNex" provided an opportunity to measure the almost continuous vertical distribution of water parameters on the scale of horizontal homogeneity of water masses, which made it possible to obtain new unique data on the properties of the spatial structure and variability of the waters of the above-mentioned water areas.

Based on the obtained field measurements, an analysis of the modern spatial distribution features of water parameters in the water area of the Dniester estuary was made.

And it was also determined the degree of influence of the approach channel from the Black Sea through the Tsaregradsky strait to the seaport Belgorod-Dnestrovsky (hereinafter referred to as SP") on the formation of specific conditions affecting the ecosystems at the estuary mouth functioning.

The initial data for the analysis of the situation were obtained during complex hydrological surveys of the Dniester estuary in September-October 2020 as part of expeditionary studies under the HydroEcoNex Project. For measurements, we used a multi-parameter hydroprobe "EXO1" from XYLEM (USA) with specialized calibrated sensors from the same company. The measurements were carried out from a motor boat. A GPS navigator was used for positioning.

The Dniester navigable approach channel (hereinafter referred to as "NAC") was dug in 1971 and has a length of 19.7 km, a width of 60 m, and a depth of 4.5 m. Salt sea water, together with marine hydrobionts, moving in the bottom layer along the NAC, got the opportunity to penetrate far into the desalinated water area of the Dniester estuary. Traffic rules in navigable channels provide that the draft of vessels must be less than the depth in the canals by at least 20 cm [4]. When ships move along the NAC, a complex circulation of water arises in it, which promotes mixing, enrichment of water masses with oxygen and weakening their stratification. The intensity of navigation along the NAC to the SP has sharply decreased in recent years; therefore, it can be assumed that specific hydrological and hydrochemical conditions have arisen in the estuary, which in a certain way affect the vital activity of ecosystems.

The following water parameters were practically obtained, for the entire water area of the Dniester estuary, from the surface to the bottom: temperature, salinity, dissolved oxygen, mineralization and turbidity. Discreteness of sampling was at 500 milliseconds.

The sampling discreteness by layers did not exceed one centimeter (the pressure sensor resolution is 4 mm) on the survey verticals, where complex hydrological conditions were noted. The declared density of data collection, up to this point, has not yet been involved in the Dniester estuary, thus the obtained data made it possible to describe in more detail the features of the structure and reveal new features of hydrophysical fields in comparison with previous studies [4]. Brief technical characteristics of EXO1 hydroprobe sensors [5].

It should be noted, that the survey of the Dniester estuary water area was carried out for two days (October 23 and 24, 2020), so we observed and describe the three-dimensional structure of the estuary waters. Wind speeds more than 8 m/s were not recorded during October 2020. Southwestern wind from 1 to 5 m/s was constantly acting for more than three days from October 21. Thus, the survey was carried out practically at a stationary (in modulus) wind field and a steady spatial structure of the estuary waters, typical for the autumn season.

The hydrophysical fields homogeneity scale in the shallow estuary and the hydrodynamic conditions in its water area make it possible to describe in a fairly complete volume the main features of these fields, having analyzed the variability of only the surface and bottom layers.

The spatial distribution of the water salinity of the Dniester estuary in the surface and bottom layers is shown in Fig. 17. The surface structure of the salinity field is determined by: the interaction of the waters of the estuary itself with the freshwater runoff of the Dniester; water exchange with sea waters (through the Tsaregradsky strait); and wind action. The salinity of the northern part of the estuary (less than 0.6 PSU, Fig. 17a) is almost completely determined by the Dniester runoff. The salinity of the river waters of the lower Dniester fluctuates in the range of 0.19-0.37 PSU). In the northern part of the estuary, there is a water mass that is practically homogeneous in terms of thermohaline parameters, filling this entire part of the water area and formed by the hydrometeorological conditions described above. The southern part of the estuary is occupied by estuary waters with a salinity of 1-5 PSU, which have already been transformed when interacting with sea water. The intermediate-frontal gradient zone, peculiar in salinity, is located in the middle and narrow part of the estuary and separates the fresh waters of the northern water area and the actual estuary water mass in the southern part. A feature of this zone is the presence of areas of high salinity gradients in the SP area, which gradually erode in the northeastern direction. This is due to the configuration of the banks and hydrodynamic processes of interaction between river and estuary waters.

The structure of the bottom salinity field, Fig. 17b, has specific features that were first identified for the Dniester estuary water area. In the southern part of the estuary, the salinity of bottom waters (1-5 PSU) is due to the interaction of sea and estuary waters. The main feature of the salinity field is the presence of a seawater wedge (with salinity up to 14.4 PSU), which penetrates through the 4.5 m deep NAC (with an average estuary depth in this part of less than 2 m. As a general feature of the salinity field structure, we note that a weak wind from the south and southwest contributed to the "shift" of the estuary water upper layer throughout the entire water area in the northeast direction, and its place was filled with less saline water due to currents of the surface layers directed towards the southern, lower part of the estuary; therefore, the salinity near the western coast is less than that of the eastern one, Fig. 1a. Thus, four water masses of the Dniester estuary should be distinguished: fresh waters of the northern water area (salinity less than 0.6 PSU); intermediate frontal waters in the central and narrow area (0.6-2.0 PSU); directly estuary waters in the southern part (2.0-5.0 PSU); and sea waters in the NAC (more than 10 PSU).

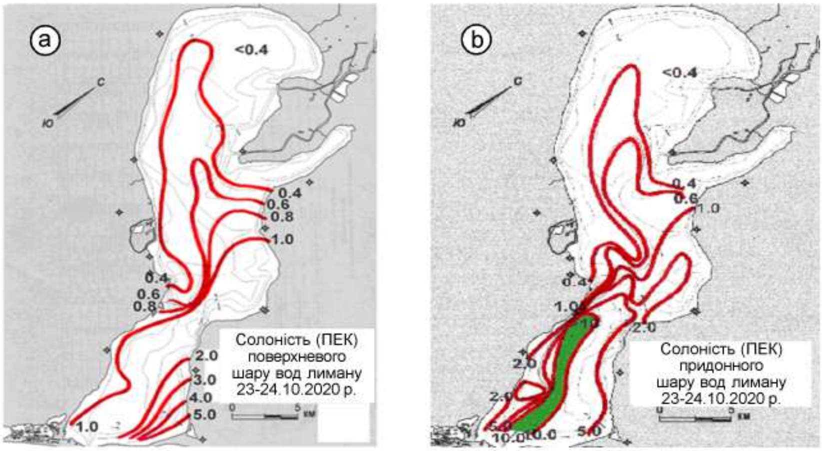


Fig. 17. Spatial distribution of the Dniester estuary water salinity according to the results of a complex hydrophysical survey on October 23-24, 2020:
a) the surface layer, b) the bottom layer. (The geographic diagram of the boundaries and bottom bathymetry of the Dniester estuary is taken from [4])

The water temperature field during the expedition was practically uniform (14.5-15.5 °C), except for the temperature of the water mass in the NAC zone, the vertical structure of which will be described below. Thus, it can be noted that all water masses of the estuary have practically the same water temperature in the autumn period, which is generally predetermined by the weather conditions of the season.

The spatial structure of the surface and bottom waters mineralization generally agrees with the hydrological and hydrobiological processes taking place in the estuary.

As already noted, the northern part of the estuary is under the influence of the Dniester runoff, therefore, here salinity has values of 400-600 mg/l typical for fresh waters. The commissioning of the Dniester HPP led to a noticeable smoothing of the seasonal hydrograph of the Dniester runoff and reduced the intensity of runoff through the estuary. As a result, the accumulation of mineral and organic compounds of nitrogen and phosphorus has increased in the estuary, water bloom has become a common phenomenon, as well as the appearance of hypoxia zones. On the other hand, the NAC contributed to an increase in the inflow of seawater into the estuary water area and, accordingly, to a mineralization increase. The mineralization of water masses in the southern part of the estuary increases towards the sea from 1000 to 5000 mg/l. The zone of the NAC stands out especially, the mineralization here is more than 15 g/l, which significantly exceeds the background value.

The estuary waters in the central and southern parts, with the exception of a thin bottom layer of 5-20 cm, contain at least 95 % of dissolved oxygen, and in some zones, values of more than 140% were recorded, what is typical for polytrophic and hypertrophic waters and indicates their significant pollution [4]. The zones in which the oxygen content at the bottom is less than 100 % (and in the rest of the water area in the entire volume of water the saturation is more than 100 %) are shown in Fig. 18. Two isolated zones with oxygen saturation less than 50 % were clearly determined in the bottom layer of the northern and central regions of the Dniester estuary. These zones were also noted during the expeditionary work on September 14, 2020, Fig. 18b. The expedition in September 2020 carried out observations in the middle sector of the estuary, from the mouth of the Glubokiy Turunchuk river, down to the narrow part of the estuary, between Belgorod-Dnestrovsky city and Roksolany village, Fig. 18b. The higher water temperature (about 22 °C) during the survey on September 14, 2020 led to an expansion of the hypoxic zone compared to that recorded during the survey at the end of October. The metabolic activity of aquatic organisms, which is caused by an increase in the amount of dissolved and suspended forms of nitrogen in river and estuary waters in warm seasons, became especially active after the regulation of the river flow. Destructive processes intensified in autumn, during the low-water period, and caused a deficiency of dissolved oxygen in the bottom layers, in places with low water exchange, especially in the northwestern part of the estuary and at the Sukholuzhie area.

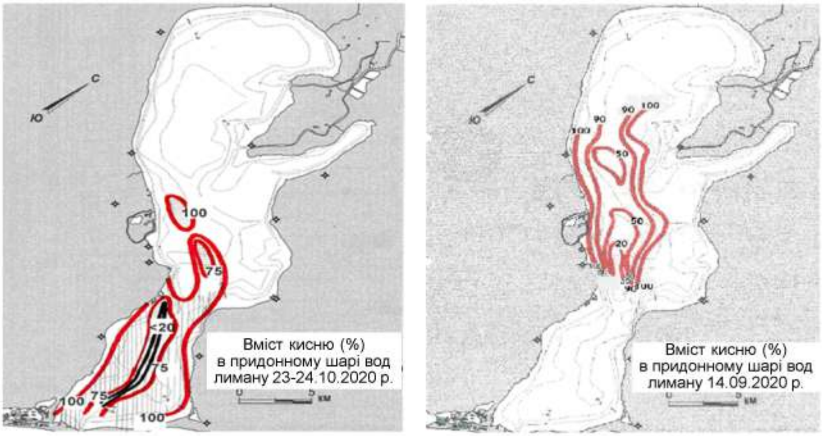


Fig. 18. Spatial distribution of the content of dissolved oxygen (%) in the bottom layer of the Dniester estuary waters based on the results of complex hydrophysical surveys in September-October 2020

A certain deficit in the oxygen content in the bottom layer is observed practically throughout the entire water area of the southern part of the estuary, with the exception of the coastal zones. The NAK zone forms a water mass, which has a separate hydrological regime and characteristics that differ from the rest of the estuary. The NAK is one of the main ways of penetration of seawater in the bottom layer into the overlying sections of the estuary. The invasion of seawater into the estuary in conditions of low water, with a decrease in the river flow for natural reasons or due to the interception of the flow by reservoirs, during strong surge phenomena, can oppress not only the freshwater delta ecosystem, but also create threats in the river bed itself, in places of fresh water intake for water supply [4].

Let us consider the graphs of the vertical distribution of the hydrological and hydrochemical parameters of the waters at the station located directly in the NAC in the area of the SP (Fig. 19).

Figures 19a,b clearly show sharp jumps in the values of salinity and water temperature, which form a halocline and a thermocline, respectively, a pycnocline is created in the density field. The uniqueness of the hydrological situation lies in the fact that, in contrast to the negative density gradient created by an increase in temperature to the bottom, an increase in salinity is a more significant factor for creating a sharp pycnocline.

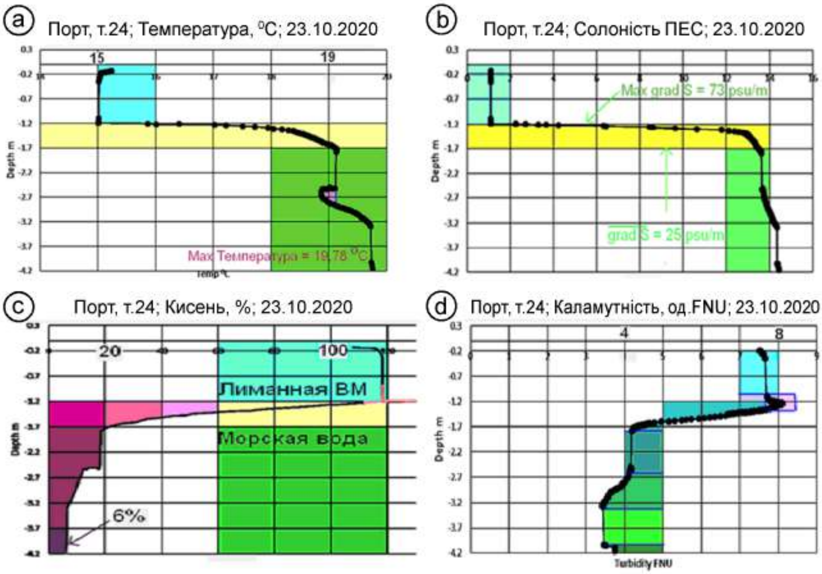


Fig. 19. Graphs of vertical distribution: a) temperature, b) salinity, c) dissolved oxygen, d) water turbidity of the Dniester estuary on the spot at the entrance to the SP according to the results of a complex hydrophysical survey on October 23-24, 2020

The pycnocline prevents the penetration of oxygen into the underlying layers and promotes the accumulation of hydrogen sulfide at the bottom in the absence of mechanical mixing. Detritus accumulates on isopycnic surfaces in the water column in the NAC and in the port water area. Low current velocities, natural and artificial isolation of the NAC and SP waters accelerate the formation of a pycnocline in comparison with neighboring estuary sections and create noticeable differences in the hydrophysical and hydrochemical characteristics of water.

In fact, a two-layer structure (homogeneous for each layer vertically) is observed, in the upper part of which there is estuary water mass, and in the lower part there is seawater with its own specific water masses characteristics. The upper layer of the estuary water with a thickness of 1.2 m has a water temperature characteristic as the entire estuary — about 15 °C and salinity of about 1 PES. The lower layer — from 1.7 m to the bottom has a noticeably higher temperature of 17-20 °C and salinity — 13.8-14.2 PSU. Sea water obtained such characteristics in September. That is, water exchange in the NAC did not occur for at least about a month. The upper and lower water masses are separated by a density jump layer, the thickness of which is only 0.5 m, but with very high values of the average gradients over the layer: for temperature — 4°C/m, salinity — up to 25 PSU/m. The indicated values of the gradients have never been before recorded in the water area of the Dniester estuary.

The formation of a sharp pycnocline in semi-enclosed water areas serves as a "hard cover" that prevents the penetration of oxygen into the interior and contributes to its almost complete consumption in the bottom layer. In the NAC and adjacent areas in the hot summer-autumn period, saprobiotic conditions are created, and the death of bottom fauna may occur. From the bottom layer, not only biogenic substances, but also hydrogen sulfide and other gases (methane, ammonia, mercaptans, etc.), formed during the decomposition of organic matter under anoxia and hypoxia, enter the water column and even into the surface layer. This is evidenced by the graph of the vertical distribution of dissolved oxygen, Fig. 19c. If oxygen saturation in the upper layer reaches 120 % or more, then below the pycnocline its content in the waters decreases from 20 % under the jump layer to 6 % at the bottom.

The vertical distribution of water turbidity can supplement information on the fine-structured features of the hydrological and hydrobiological characteristics of waters, Fig. 19d. The surface water of the Dniester estuary had a turbidity in the central part of 8-10 NFU, in the northern part — 13-19 NFU, in the southern — 11-17 NFU, and in the near-surface layer, from 0 to 5 cm, the turbidity values were about 2-5 units above.

Formally, the ratio between the unit of turbidity in terms of formazin and the solid particles amount in water of 1unit FNU corresponds to the content of 0.58 mg/l of kaolin [4]. Liman water which occupies the upper layer with a thickness of 1.2 m has a value of about 7.8 FNU (excluding the upper 5 cm). The vertical variation of oxygen and turbidity in a thin about 3 cm thick layer on the 1.20 m horizon is abnormally released and indicates that it is a hypertrophic layer with a higher oxygen content — 128 % (+10 %) and solid suspended particles — 8.11 NFU (+0.3 FNU units) than in the higher and lower horizons (most likely, detritus and dead organic matter are concentrated in this thin layer). This layer cannot go dipper due to large gradients of water density, i.e. it is located at the interface between two dissimilar water masses.

In the boundary layer, the turbidity values decrease to 4.30 units. The turbidity continues to decrease to 3.41 NFU further from the layer, practically correlating with the change (decrease) in the amount of oxygen with depth, Fig. 19c,d. Obviously, with a decrease in the amount of dissolved oxygen in the seawater of the NAC, its transparency increases, since turbid estuary waters rich in suspended solids cannot penetrate into these layers. A similar phenomenon is observed on the seashore during the upwelling of deep sea waters, when very cold, but transparent and “contaminated” with hydrogen sulfide waters come to the shore under the action of the wind of the corresponding directions.

Expeditionary studies of the spatial structure of the waters of the Dniester estuary made it possible for the first time to reveal sharp differences in the values of the hydrophysical characteristics of the waters of the estuary and the waters of the NAC.

The features of the spatial structure of the salinity field of the estuary waters made it possible to distinguish four water masses.

The relatively stationary zones of the estuary water area where the oxygen content in the bottom waters is less than 50 % have been determined. Sharp differences in the values of temperature, salinity, mineralization, turbidity, and the content of dissolved oxygen in the vertical structure of water in the NAC were revealed for the first time. These differences are due to the lack of navigation in the Channel. Significant gradients of temperature and salinity in the PC (-4^{0}C/m and up to 25 PSU/m, respectively) create a powerful pycnocline under certain hydrometeorological conditions.

The content of dissolved oxygen decreases from 20 % to 6 % under the pycnocline in the bottom and middle layers of the NAC; therefore, these layers may contain hydrogen sulphide. The redox line may rise into the water column in some situations. This leads to a significant deterioration of ecological conditions in the waters of the estuary and the oppression of the biota living in it.

The flow pass through the estuary has noticeably slowed down, the accumulation of mineral and organic compounds of nitrogen and phosphorus has increased primarily because of the regulation of the Dniester runoff. Large values of the content of dissolved oxygen and mineralization in the waters indicate unfavorable biochemical processes in the estuary. “Blooming” of waters has become a common phenomenon, as well as the appearance of hypoxia zones, that is characterized of significantly polluted polytrophic and hypertrophic waters.

Salt water wedge penetration distance calculation

The length of the halocline, or the distance that the halocline is able to penetrate into the estuary, can be calculated analytically, in particular, based on the hydraulic model of the salt wedge in the channel. [6].

The solution of the initial differential equations of motion in this model, under certain conditions, gives a design equation for calculating the length L of the advancement of the wedge of salty sea waters.

To solve the problem, the data of field measurements were used. The data were obtained during expeditionary work carried out by the authors on October 23-24, 2020 in the water area of the Dniester estuary. The hydrological data on the river flow are calculated according to the hydrological station Mayaki observations. Data on water levels, wind directions and speed were taken at the points of hydrometeorological observations at Belgorod-Dnestrovsky and Tsaregradsky strait (Tsaregradskoe girlo).

Calculations have shown that under the conditions that were adopted in the formulation of the problem, sea water is capable of moving up the estuary at a distance of more than 17.6 km (17 680 m).

Actual measurements of the characteristics of the water mass were carried out on October 23-24, 2020 in the area of the port of Belgorod-Dnestrovsky, (Fig. 19b,20) and in the area of the navigable canal. Measurements showed the presence of a wedge of dense seawater with a salinity of 14.5 ‰ at a distance of more than 14 km from the Tsaregradsky strait alignment.

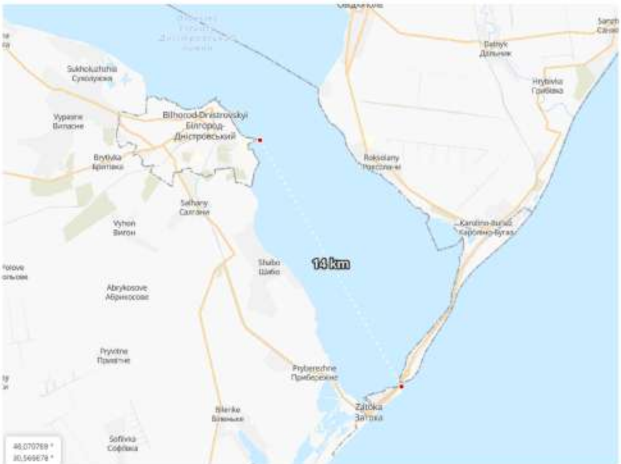


Fig. 20. Location of the 24th survey vertical near the Belgorod Dnestrovsky port water area

A salt water layer of 14.5 ‰ was found at depths from 1.2 m to 4.2 m. The upper layer of the Liman water from the surface to a depth of 1.2 m has a salinity of 1.1 ‰ (Fig. 19b).

To account for the effect of bottom topography on halocline dynamics, a model was built that includes parameters related to bottom slope, depth change, and water surface slope. The model is built on the assumption that the pressure gradient in the halocline along the length $\partial P/\partial x = 0$ and along its width $\partial P/\partial y = 0$, and the pressure gradient along the depth is equal to:

$$\frac{\partial P}{\partial H} = -\int_{h}^{0} \rho g dh$$, where P is the pressure in the halocline layer from 0 to H.

As a result, a mathematical expression was obtained for calculating the length L of advancement of the salt water wedge. The streams inside the halocline are also taken to be close to zero, and the slopes are a function of only the length:

$$L = \frac{\Delta p}{p_0} \frac{H}{Iw + Ib\frac{\Delta p}{p_0}} \quad (7)$$

Where: ***Iw*** is the average slope of the water surface;

Ib — the slope of the bottom.

In this situation, a wedge of salt water, when moving along the navigable canal to the port water area, in its upper part collides with the rise of the bottom of the estuary, where the depth difference varies from 4 to 2 meters.

To calculate the penetration halocline length according to formula (7), a segment of the bottom was taken. The segment runs from the beginning of the navigable canal, at a depth of 4.2 m, to a point in the direction to the Dniester river mouth.

To calculate the penetration length of the halocline according to the numerical hydrodynamic model, a section of the bottom was taken, from the beginning of the navigable channel, at a depth of 4.2 m, to a point in the direction of the mouth of the Dniester River, at a distance obtained by formula (7), i.e. at 17680 m. The bottom elevation at this point is about 2.0 m. The measured density of water at the beginning of the halocline is 1.017 g/cm³, the density of water in the estuary is 1.001.

This segment bottom slope Ib = 0,000314

The slope of the water surface, Iw, at the site can be taken close to 0, if we take into account the water level at the town of Mayaki and the level at the town of Belgorod Dnestrovsky at the design moment. Then by formula (7) we get the value: L= 33751,7 (m) = 33,75 (km).

The result, obtained analytically using the numerical hydrodynamic model, was practically confirmed by observational data during expeditionary work in the water area of the Dniester estuary on September 9, 10, 11, 2021.

In particular, waters with salinity of 8.1 ‰ was recorded at point 80, at a distance more than 28 km from the Tsaregradsky strait (Fig. 21, 22); at point 90, at 23.9 km from Tsaregradsky strait — 10.2 ‰; at point 120 the salinity was increasing from 4.4 ‰ at the surface to 12.5 ‰ in the bottom layer at a depth of 1.2 m to 2.3 m.

Fig. 21. The survey 80, 90, 120 verticals location in the water area of the Dniester estuary, 9-11 September 2021.

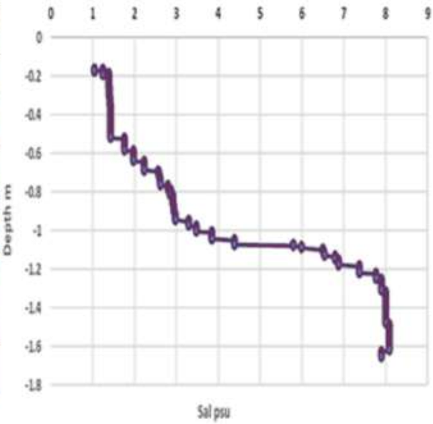


Fig. 22. Distribution of salinity over depth at point 80, 09-09-2021

4. Climatic changes in temperature and precipitation fields

Studies of recent decades indicate that numerical regional climate models are quite effective in predicting the impact of anthropogenic impact on the background of climate change. Regional models more accurately describe the state of the "atmosphere — underlying surface" system in comparison with global models. We used the regional climate model RegCM4.7 [7]. The RegCM4.7 model used a new approach to identifying future greenhouse gas emissions: typical (representative) concentration paths (RCPs) were applied. Studies were carried out based on three scenarios: RCP2.6, RCP4.5 and RCP8.5, which assume an increase in radiative forcing by 2.6, 4.5 and 8.5 W/m^2, respectively. Here are the simulation results for the moderate RCP4.5 scenarios for the period 2021-2029.

Numerical experiments were carried out for four simulated sections (Table 1) of the middle and lower part of the Dniester watershed, for which preliminary studies have shown spatial homogeneity of climatic variability. The calculations were carried out with a spatial step of 20 × 20 km and a time step of 150 sec.

The coordinates of the sections in the catchment area of the middle and lower part of the Dniester River are given in Table 1.

Table 1. Coordinates of the Dniester catchment sections for which the modeling of climatic variability was carried out

Section	Coordinates	
1	28,75-30,25 E;	46,50-47,25 N
2	27,75-29,50 E;	47,25-48,00 N
3	27,25-28,75 E;	48,00-49,00 N
4	26,50-27,25 E;	48,50-49,25 N

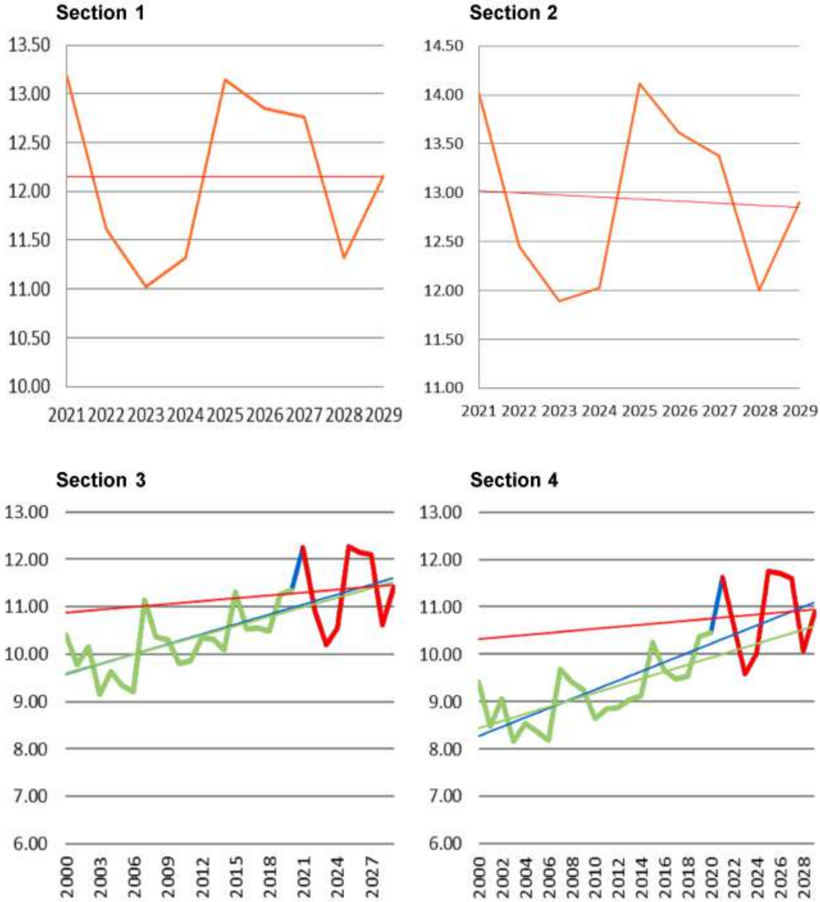
To assess the climatic trend of atmospheric parameters (air temperature and precipitation) in these areas, we also used the data of standard meteorological observations of stations located on the territory of these sections, Table 2. We do not show regressions for the average annual air temperature in sections 1 and 2 for the period 2000-2020 due to significant gaps in the time series of observations (Fig. 23).

Table 2. Coordinates of hydrometeorological stations at which atmospheric parameters were measured in the simulated sections

Station name	Latitude	Longitude	Section number
Stefan Wode	46,52	29,48	1
Rozdelnaya	46,85	30,08	1
Chisinau	47,02	28,98	1
Rybnitsa	47,77	29,02	2
Beltsi	47,78	27,95	2
Kam'yanka	48,03	28,70	3
Soroki	48,20	28,30	3
M.Podolsky	48,45	27,78	3
N.Ushitsa	48,85	27,27	4
K.Podolsky	48,65	26,67	4

In Fig. 23,24 shows the time series of variability of atmospheric parameters for different periods: observed data 2000-2020, forecast by the RegCM4.7 model 2021-2030, as well as linear trends for three time periods: 2000-2020, 2021-2030, 2000-2030. Fig. 23 shows the average annual variability and trends temperature, while Figures 24 show the average seasonal variability precipitation and its linear trends.

Temperature



Legend: graphs of observed and forecast data for the specified periods and their trend lines:

2021-2029 (red)	2000-2020 (green)	2020-2029 (blue)

Fig. 23. Average annual values of air temperature in the watershed areas of the Dniester River

The main feature of changes in air temperature over the analyzed periods (Fig. 23) is a decrease in the growth rate of the average annual temperature (the slope of the red line is less than that of the blue and green lines); we also note that in sector 2 the trend has a negative value for the forecast period 2021-2029.

The amount of precipitation on an average annual scale will decrease for all modeling sites (Fig. 24). Note that the positive trend of the first two decades, indicating an increase in precipitation in sectors 1 and 2, is reversed.

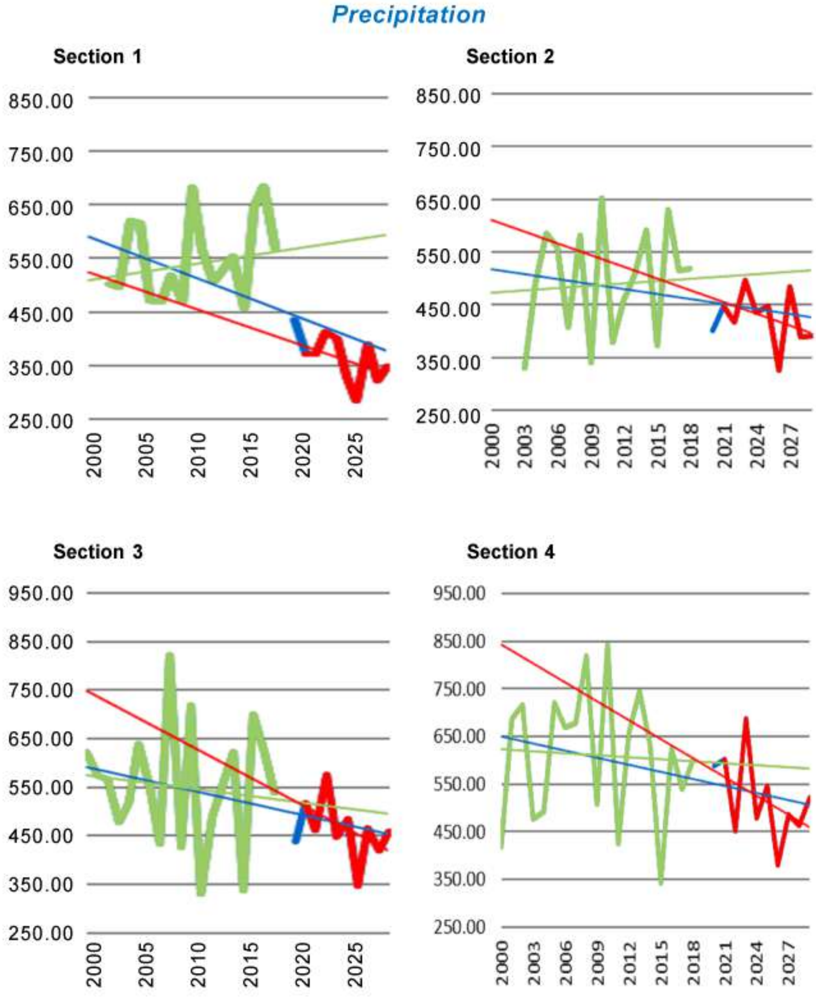


Fig. 24. Average annual values of the precipitation in the watershed areas of the Dniester River

Analysis of the graphs of changes in the average seasonal values of air temperature (Fig. 25) indicates a tendency for its increase, with the exception of the summer months. The temperature growth rate is highest in the winter season, but in spring and autumn it tends to decrease compared to the period 2000-2020.

Changes in the amount of precipitation (Fig. 26) in these areas indicate a further decrease. Note that a characteristic feature of the trends is a significant decrease in precipitation in the winter season with a gradual slowdown in the rate of decrease in the spring and summer seasons, and even their increase is predicted in the autumn season.

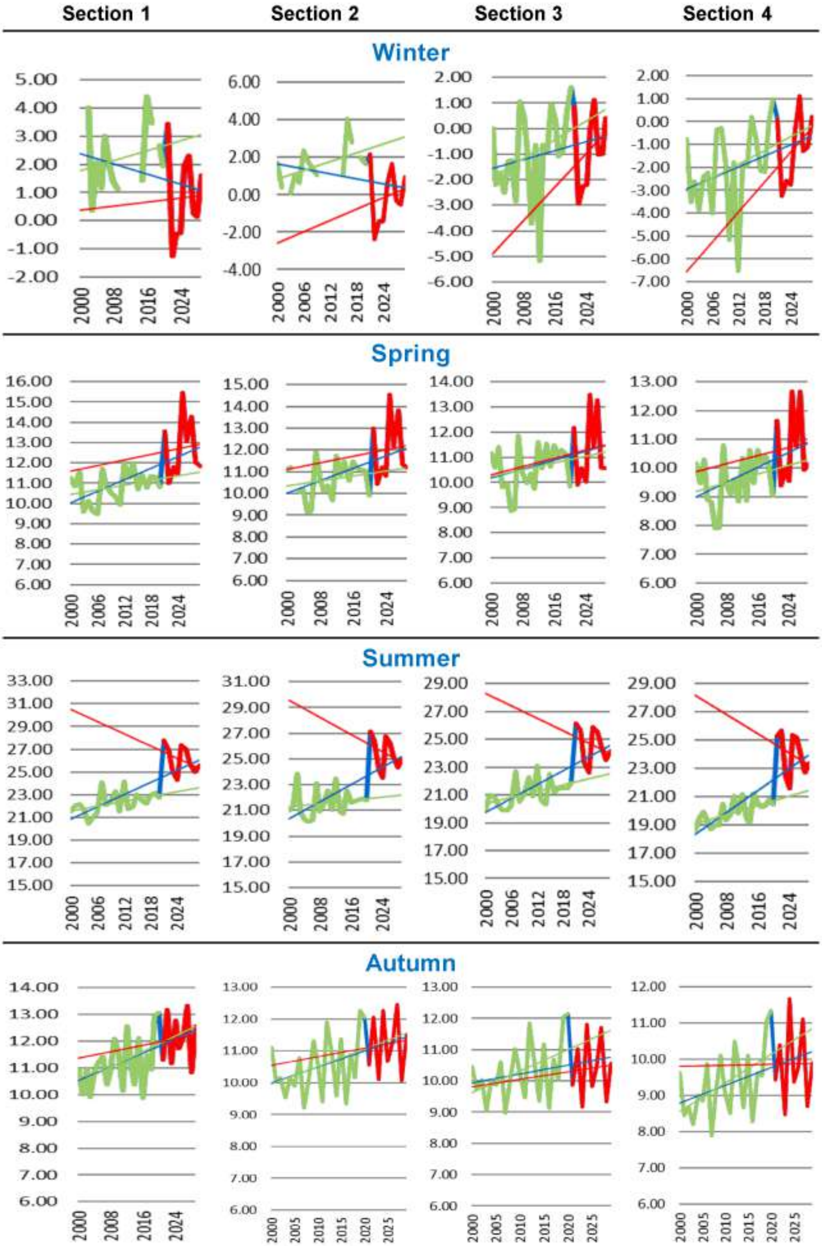


Fig. 25 Observed and prognostic seasonal variability and air temperature trends for sections of the middle and lower Dniester 2000-2029

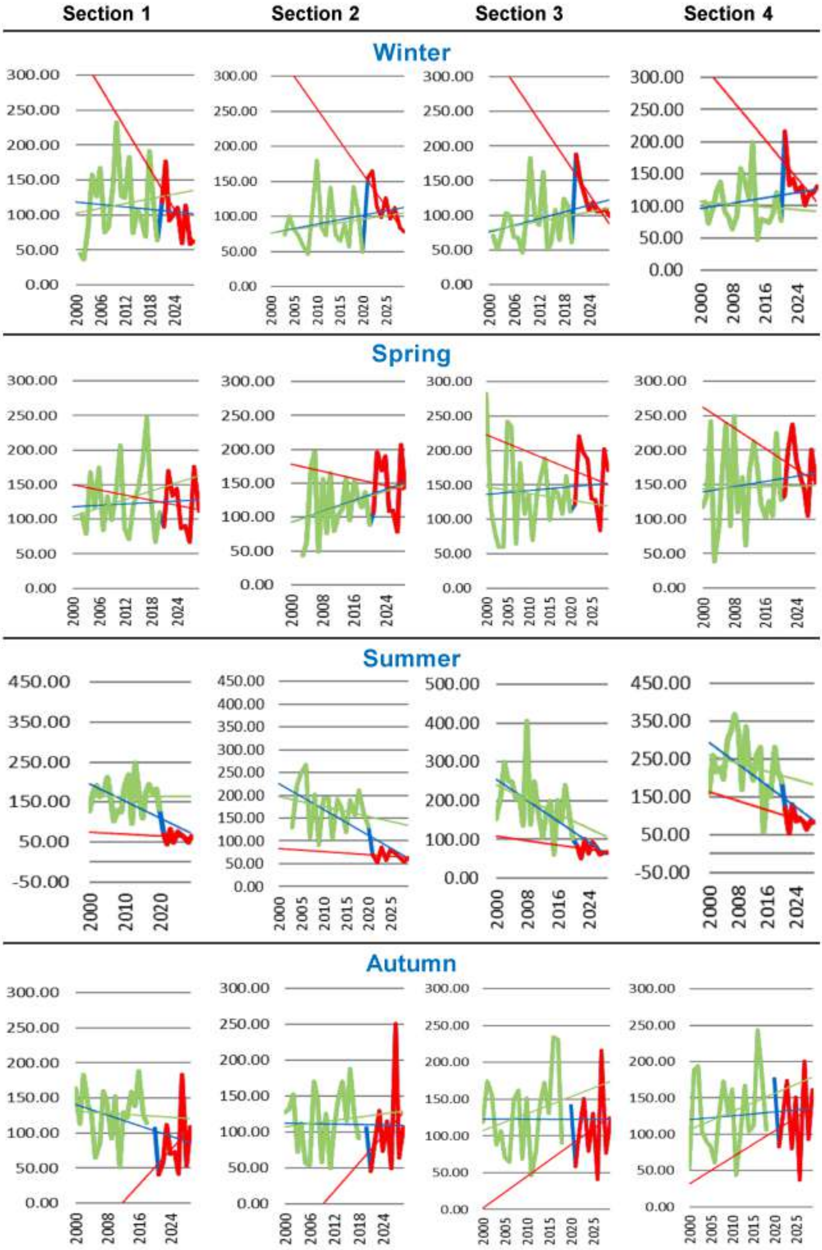


Fig. 26. Observed and predicted seasonal variability and precipitation trends for the middle and lower Dniester regions 2000-2029

5. Knowledge dissemination (broadcast)

Public awareness about the importance of the HydroEcoNex objectives and its' results is the one of the pillar for the Project successful implementation.

Broadcasting and dissemination of the Project objectives usually done through the press and science publications, online media, radio and TV, promotional materials, such as leaflets and brochures and public events.

Fig. 27. Project launching in Chisinau, November, 12 (left) and in Odessa, December, 12, 2018

With the aim to attract the public attention and to highlight the beginning of the Project, the launching conferences were organised in three neighbouring countries: Moldova, Romania and Ukraine.

Invitation were sent to the relevant decision makers, scientists, researchers, university staff, students, NGOs, media and the general public.

The events were widely broadcasted, as the Project had inspired lots of interest, due to its very urgent and important issues — the synergistic impact of both hydropower and climate change on ecosystems of the rivers r. Dniester and r. Prut.

The fact that our public, local government and administration feel very strongly about the environmental issues, was proven by the noticeable and consistent interest of decision making bodies to the problems addressed by the Project and its Launching conferences, such as:

- The State Secretary of the Ministry of Education, Culture and Research of the Republic of Moldova Elena Belei has attended the launching of Project events in Chisinau and

- The Senior Members of Odessa City Administration took part in launching the Project and have attended the conference.

Fig. 28. The first HydroEcoNex press conference, 2018, Chisinau

On agenda were the discussion of the major issues of public interest, such as: current ecological state of the Dniester River, development of the Upper Dniester hydropower complex in Ukraine, building and managing the dams along the course of our rivers, highlighting the importance of spring floods for the river ecosystems, and the role of internationals projects in the study of the Black Sea.

The HydroEcoNex team have discussed major environmental problems, raised by the Project and widely broadcasted it on Moldova and Ukrainian Radio and TV (Moldova 1 TV, TVR Moldova, RTR Moldova, Sputnik Moldova, Radio Europa Libera Moldova) and (Odessa channel 1 Pervii Gorodskoi, Odessa 7 News channel).

On the 22 May 2021, the day of biodiversity, UkrSCES and HMC BAS held two public seminars based on the results of the project BSB165.

The first seminar was organized for schoolchildren in the school of the Maiaky village. The seminar was held as a part of the Ecological Forum "Children of the Dniester", organized by the Lower Dniester National Park. The public seminar was attended by more than 100 schoolchildren aged 12-14 from 7 schools of 5 localities of Odessa region (Maiaky, Bilyaevka, Yasky, Yosypivka, Nadlymanske).

At the seminar, schoolchildren had opportunity to listen to the reports and to have an open discussion there with three Project leading environmental scientists: Svitlana Kovalyshyna (Project coordinator PB4 BSB165), Elena Zubcov (Project Manager BSB 165 LP) and Alexander Matygin (Project coordinator PB5 BSB165).

In return, as a part of the forum, children have presented their own or their school team ecological projects, put on display their drawings and took part in the competition and quizzes on the topic of the river Dniester ecology.

The second public seminar was held on the 22nd of May 2021, and was organized for the 3rd year students of The Odessa State Ecological University (OSEU), specialty "Ecology".

Twenty three OSEU students took active part in this public seminar and further discussion of the reports, presented by of Svitlana Kovalyshyna, Elena Zubcov, Alexander Matygin.

On the 2nd of September, 2021,the Project team from Ukraine took part in an open seminar in Romania, organized by Partner — University Dunarea de Jos Galati.

The member of the seminar discussed in details the problems of the ecosystem of the river Prut and river Dniester in content with the HydroEcoNex Project.

Fig. 29. HydroEcoNex Team — Participants in an open workshop in Romania on September 2, 2021

6. Knowledge Transfer Workshop

The workshop “Decline in discharge of the freshwater flow into the Black Sea due to the impact of the hydropower management and climate change” took place in Odessa during period if three days: 12-14 December 2019 and was organised by the Ukrainian Scientific Centre of the Ecology of Sea.

The participants of the event were members of HydroEcoNex team (Institute of Zoology, International Association of River Keepers “Eco-Tiras” and Hydrometeorological Centre of Black and Azov Sea), as well as representatives from other institutions, such as The Odessa Regional Administration and The Odessa State Environmental department.

The workshop discussion was focused on the issue of the decline in discharge of the freshwater flow into the Black Sea due to the effect of the hydropower management regime and its recent development and the global climate changes. The participants shared historic and recent data on the water quality, based on the physicochemical parameters. Representatives of the Hydrometeorological Centre of Black and Azov Sea demonstrated the electronic database on hydrometeorological observations on rapid assessments, average daily and average annual values of the parameters of the atmosphere and the river Dniester for the period from the beginning of the observational station's operation till the present time.

Fig. 30. HydroEcoNex team participants in the first knowledge transfer workshop, Odessa, December, 13, 2019

An important item on the agenda of the seminar was — the discussion of the first draft of the Strategy for bilateral cooperation on the joint monitoring of the transboundary rivers, affected by the hydropower, which will be reported and delivered to the decision-makers.

On the 26-27 August 2021, HMC BAS held the Knowledge Transfer Workshop and Steering Committee Meeting, where the results of the research within the framework of the HydroEcoNex were presented by team researching scientists from UkrSCES, Institute of Zoology Republic of Moldova, "Eco-Tiras", Lower Dniester National Park and Odessa National University I. Mechnikov.

Fig. 31. HydroEcoNex Team Participants in an open workshop in Odessa on August, 26-27, 2021.

At that Seminar the Conclusive Results were presented, that described the summary of the changes in the ecosystems of the rivers r. Prut and r. Dniester, due to the impact of the construction of hydroelectric power plants and climate change.

The conclusive estimates of the oxygen regime in the reservoirs of the lower Dniester were presented, as well as the estimates of the climatic changes in atmospheric parameters (air temperature and precipitation) before 2030 in the area of the River Dniester watershed [8].

7. International conferences

The International Conference "Impact of the Hydropower industry on the Functioning of the River Ecosystem" was held in Tiraspol, Moldova on the 8-9 October 2019. It was organised by the International Association of River Keepers Eco-TIRAS in cooperation with Institute of Zoology and the Taras Shevchenko Transnistria State University.

The conference provided an opportunity to bring together 120 participants — representatives of NGOs, research institutes, universities, international organizations (UNDP, OSCE) and independent consultants from Romania, Ukraine, Russian Federation, Sweden — to share current knowledge on the impact of hydropower on the functioning of transboundary ecosystems of the Dniester and Prut rivers.

The participants of the conference jointly accepted and have approved the resolution, which expresses their opinion on the current condition of the River Dniester and recommends the measures to be undertaken by decision-making bodies of the Republic of Moldova and Ukraine, in order to alleviate some of the effects of human activity in the riverbed and the River Dniester Basin.

Fig. 32. Opening ceremony of the International Conference "Hydropower Impact on River Ecosystem Functioning", Tiraspol, 8 October 2019 (left); Plenary talk by Alexander Matygin; HydroEcoNex team — participants in the Conference

EcoTiras, — the organizer of the conference, have published the proceedings of the conference — print and on-line version on http://eco-tiras.org [2, 3].

In October 17-18, 2019, the participants of the HydroEcoNex HMC BAS and Eco-Tiras took part in the work of the All-Ukrainian scientific-practical conference "River and estuaries of the Black Sea at the beginning of the XXI century" (Odesa State Environmental University. Ukraine) [9].

The original and innovative method was presented there, that allowed to extend the data and to improve the calculation of the values the river discharge for the river Dniester, by using the correlation formulas and the historical data on the level of water from respected r. Dniester Estuary stations, such as Mayaki station.

The HMC BAS team, in collaboration with other partners in the HydroEcoNex Project, also took an active part in the international environmental conferences, such as:

- “EU Integration and Management of the Dniester River Basin” (October 8-9, 2020. Chisinau, Moldova) [10-12];
- Academician Leo Berg - 145 (Bendery, Moldova — 2021) [7];
- The X-th International Conference of Zoologists “Sustainable use and protection of animal world in the context of climate change” that was organized by the Institute of Zoology (Republic Moldova) on September 16-17, 2021 [4, 13];
- The Geological Society of America. GSA Connects 2021. Portland, Oregon, USA/ GSA Topical Session, “T137. From the Caspian to Mediterranean: Environmental Change and Human Response during the Quaternary (INQUA IFG POCAS, IGCP 610)” [14, 15].

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Joint Operational Programme Black Sea Basin 2014-2020
Hydrometeorological Centre for Black and Azov Seas
September 2021

Joint Operational Programme Black Sea Basin 2014-2020 is co-financed by the European Union through the European Neighbourhood Instrument and by the participating countries: Armenia, Bulgaria, Georgia, Greece, Republic of Moldova, Romania, Turkey and Ukraine.
This publication was produced with the financial assistance of the European Union. Its contents are the sole responsibility of *Hydrometeorological Centre for Black and Azov Seas* and do not necessarily reflect the views of the European Union.